

Measurement of the flavour-specific CP violating asymmetry a_{sl}^s in \overline{B}_s^0 decay

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Abstract

The CP violating asymmetry a_{sl}^s is studied with a sample of \overline{B}_s^0 or B_s^0 semi-muonic decays in proton-proton collisions at a centre-of-mass energy of 7 TeV at LHCb with an integrated luminosity of 1 fb^{-1} . The final state studied is $D_s^\pm \mu^\mp$, with D_s^\pm reconstructed in the final state $\phi \pi^\pm$. The $D_s^\pm \mu^\mp$ yields are summed over untagged \overline{B}_s^0 and B_s^0 initial states, and integrated with respect to decay time. Data driven methods have been developed to measure all the efficiency ratios needed to determine a_{sl}^s from the measured raw asymmetry. We obtain $a_{sl}^s = (-0.24 \pm 0.54 \pm 0.33)\%$, where the first uncertainty is statistical and the second systematic.

1 Introduction

The goal of this study is the determination of CP asymmetry in \overline{B}_s^0 - B_s^0 mixing, which is a sensitive probe of new physics. In the neutral B_s mixing system the time dependent mass eigenstates are related to the weak eigenstates by a 2×2 complex matrix [1]. The measurable quantities are the mass difference $\Delta M = M_H - M_L$, the width difference $\Delta \Gamma = \Gamma_L - \Gamma_H$ and the semileptonic (flavour-specific) asymmetry a_{sl}^s . Here a small asymmetry term a_{sl}^s is defined and related to the mixing coefficients q and p :

$$a_{sl}^s = 1 - \left| \frac{q}{p} \right|^2. \quad (1)$$

In the Standard Model a_{sl}^s is tiny and beyond current measurement precision. The D0 experiment, however, measured a 3.9 standard deviation excess for a combination of a_{sl} for B^0 and B_s^0 mesons (dimuon asymmetry) that is ascribed mostly to the B_s^0 .

Extracting the direct values for a_{sl}^s and a_{sl}^d gives more independent insights. It was realized LHCb could, in principle, check this measurement, but it would be difficult.

For a hadron collider experiment, the initial production asymmetry is not necessarily zero and has to be considered in the derivation of a_{sl}^s . To the first order we have, after integrating over time, the untagged asymmetry A_{meas} :

$$A_{meas} = \frac{\Gamma[D_s^- \mu^+] - \Gamma[D_s^+ \mu^-]}{\Gamma[D_s^- \mu^+] + \Gamma[D_s^+ \mu^-]} = \frac{a_{sl}^s}{2} + \left[a_p - \frac{a_{sl}^s}{2} \right] \frac{\int_{t=0}^{\infty} e^{-\Gamma t} \cos(\delta m t) \epsilon(t) dt}{\int_{t=0}^{\infty} e^{-\Gamma t} \cosh \frac{\Delta \Gamma t}{2} \epsilon(t) dt}, \quad (2)$$

where the $\epsilon(t)$ is the detector acceptance function and the physical quantity a_{sl}^s is a factor of 2 larger than the measured untagged asymmetry A_{meas} .

In principle, we have to be concerned with particle anti-particle production asymmetries, denoted as a_p as well as detector related asymmetries, a_d . For this time integrated measurement of a_{sl}^s , one key element is based on the realization that the rapid oscillations cause any production asymmetry between B_s^0 - \bar{B}_s^0 to be diluted to a negligible level. Using $\epsilon(t)$ from MC, we have estimated integral ratio in Eq. 2 to be 0.2% for B_s^0 decays and 33% for B^0 decays. Since the initial B production asymmetry is at most only a few percent, this reduces the effect of a_p to the level of a few $\times 10^{-4}$ for B_s^0 decays, well under our goal of the uncertainty on the order of 10^{-3} .

2 Analysis Method

Our goal is to measure the difference between $D_s^+ X \mu^- \bar{\nu}$ and $D_s^- X \mu^+ \nu$, where the $D_s^\pm \rightarrow K^+ K^- \pi^\pm$. In the first measurement we restrict ourselves to D_s^+ decaying into $\phi \pi^+$, in order to reduce the effects of charge asymmetries induced by different kinematics of the K^+ and K^- in the final state as well as suppress false D_s^+ background.

We construct the measured asymmetry A_{meas} as

$$A_{meas} = \frac{\frac{N(D_s^- \mu^+)}{\epsilon(\mu^+)} - \frac{N(D_s^+ \mu^-)}{\epsilon(\mu^-)}}{\frac{N(D_s^- \mu^+)}{\epsilon(\mu^+)} + \frac{N(D_s^+ \mu^-)}{\epsilon(\mu^-)}} \quad (3)$$

where $N(D_s^\pm \mu^\mp)$ is the measured yield of $D_s^\pm \mu^\mp$ pairs and $\epsilon(\mu^\pm)$ is the efficiency for muon identification and trigger efficiency.

We use both fitting and counting (count the number of total events in mass range [1919, 2018] MeV and then subtract off the background level that is obtained from the full fit within the same window) methods to extract the signal yields, which are shown in Fig. 1. Here both the signal D_s^\pm (yellow shaded area) and D^\pm (red shaded area) are fitted by triple Gaussian functions with two Gaussian's share a common mean. The background (black dashed line) is modeled by a second order polynomial function.

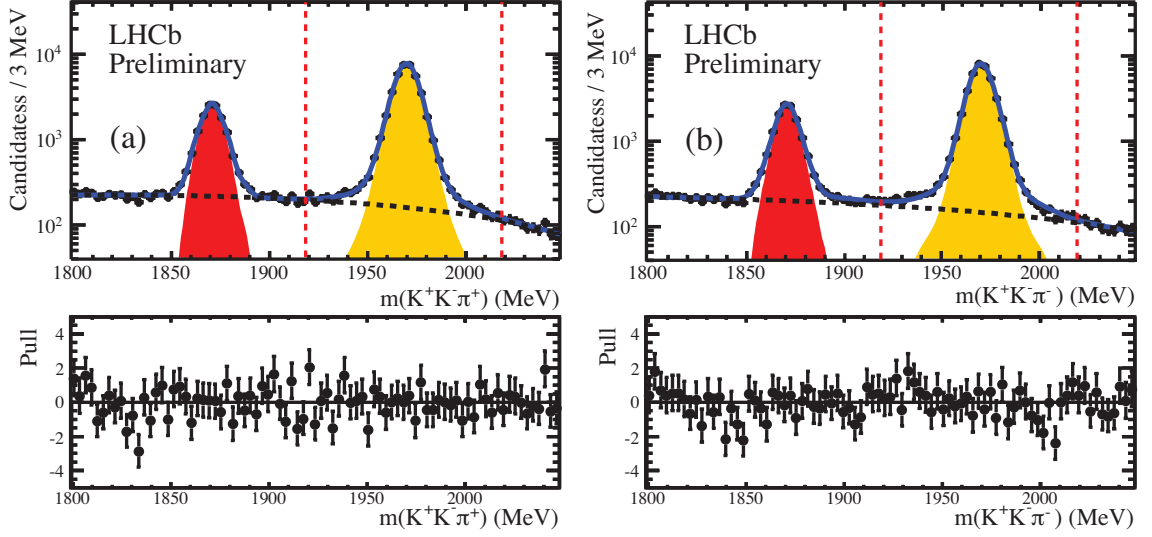


Figure 1: The invariant mass distributions for: (a) $K^+K^-\pi^+$ events and (b) $K^+K^-\pi^-$ events (only the magnet up data is shown here) with $m(K^+K^-)$ within 20 MeV of ϕ meson mass. The fitting functions are described in the text.

An elegant data-driven approach is developed to measure the pion tracking efficiency thus the relative tracking efficiency between π^+ and π^- [5]. The idea is to first “partially” reconstruct the prompt $D^{*+} \rightarrow D^0\pi_s^+$ decays where $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ with one D^0 daughter pion ignored (called partial reconstruction) and subsequently “fully” reconstruct the whole decay sequence on top of the partial reconstruction (called full reconstruction). The detection efficiency is then determined by the ratio of the full reconstruction to the partial reconstruction. The pion detection asymmetry is then examined versus both momentum and transverse momentum, and no dependence is observed. This fact simplifies calibration of the tracking asymmetry for the charge symmetric final state ($\pi^\pm\mu^\mp$ pairing). This technique is also used to measure the $D_s^+ - D_s^-$ production asymmetry [5].

To determine the muon identification and trigger efficiencies, we developed a minimal biased method to select a large sample of $J/\Psi \rightarrow \mu^+\mu^-$ events. The idea is to take fully reconstructed hadronic events such as $B \rightarrow D\pi$ that are triggered on the B hadrons, and use $J/\Psi \rightarrow \mu^+\mu^-$ decays in the same event arising from the decay of the companion b quark to give a unbiased measurement of muon efficiency.

3 Results

We form an arithmetic average of the magnet up and magnet down data. Taking the average in this manner tends to cancel any residual magnet field related biases. After correcting for muon identification and trigger asymmetry, $a_d(\mu)$, the untagged asymmetry between $D_s^- \mu^+$ and $D_s^+ \mu^-$ final states is measured as $(-0.12 \pm 0.27 \pm 0.16)\%$ with the first error statistical and second systematic. Multiplied by a factor of two as shown in Eq. 2, the physical quantity $a_{sl}^s = (-0.24 \pm 0.54 \pm 0.33)\%$ [4].

The predictions in the Standard Model for semileptonic asymmetries in B_s^0 and B_d^0 decays are $a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5}$, and $a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4}$ [2]. Our measurement is consistent with the SM prediction.

We show in Fig. 2 our measurement, the D0 dimuon result, the previous D0 measurement using flavour tagged $D_s^\mp \mu^\pm$ events in a 5 fb^{-1} sample [3], that gives a value of $a_{sl}^s = (-0.17 \pm 0.91_{-0.15}^{+0.14})\%$ ¹, and the average value of a_{sl}^d from $\Upsilon(4S)$ measurements of $(-0.05 \pm 0.56)\%$.

In conclusion, our result a_{sl}^s is the most precise determination to date, and is in agreement with the Standard Model prediction and D0 results.

Acknowledgement

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¹An updated measurement performed by D0 which supersedes this one results in $a_{sl}^s = (-1.08 \pm 0.72 \pm 0.17)\%$. In combination with the D0 dimuon asymmetry this gives a combined result of $a_{sl}^s = (-1.70 \pm 0.56)\%$.

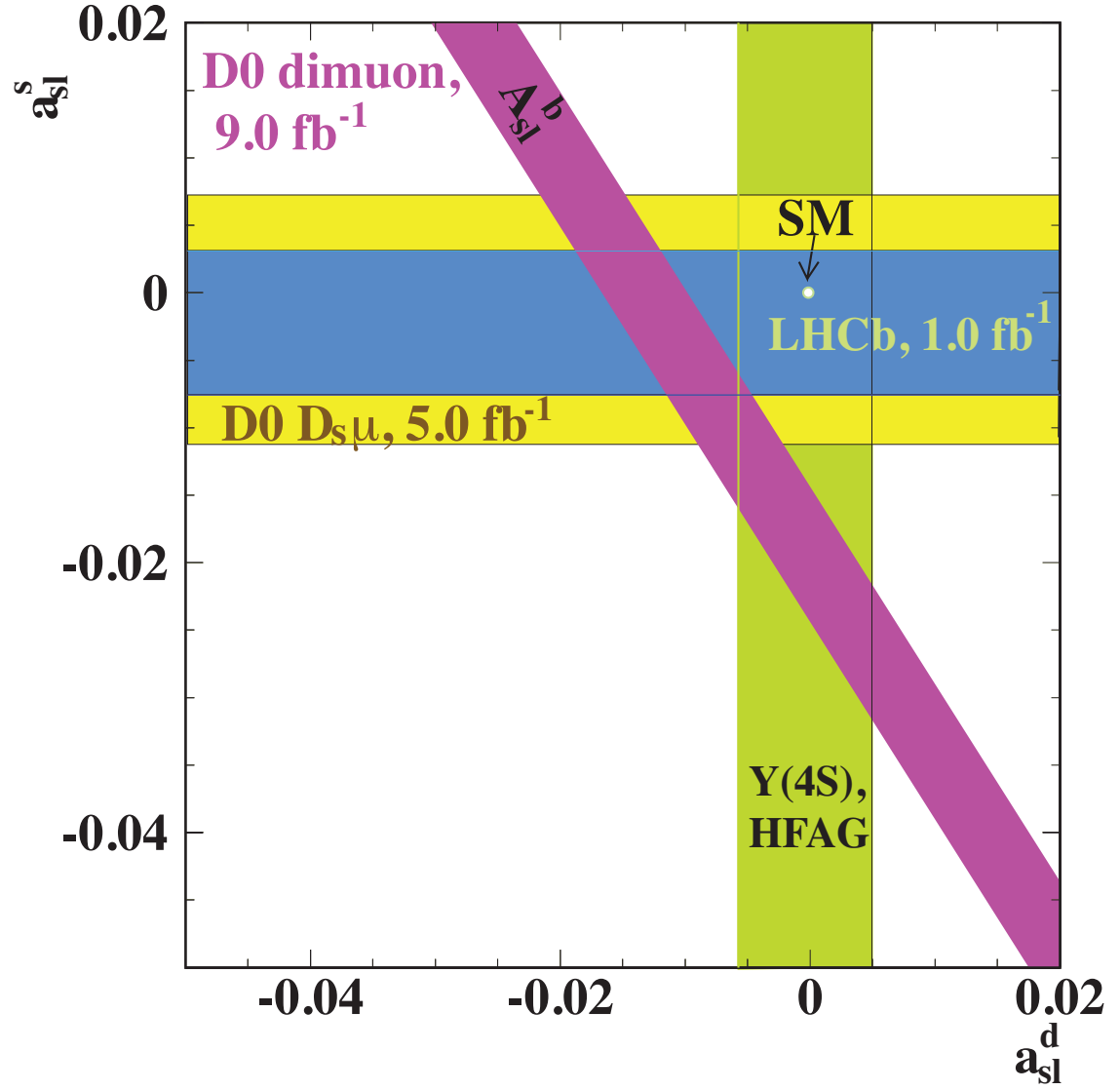


Figure 2: Measurements of semileptonic decay asymmetries. The bands correspond to the central values ± 1 standard deviation, defined as the sum in quadrature of the statistical and systematic errors..